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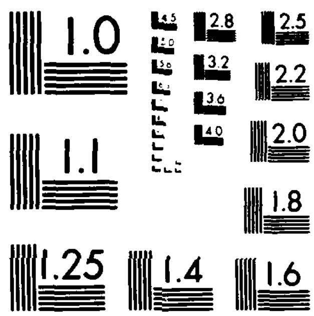

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A Model for the Estimation of Rain Distributions

R. O. BERTHEL
V. G. PLANK

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METEOROLOGY DIVISION PROJECT 6670
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-The adverse attenuation effects caused by rain or snow on electro-optical weapons and communication systems are important considerations in any military operation. Attenuation is a function of the E-O wavelength and the number, size, and type of precipitation or cloud particles. The amount (liquid-water-content) and type of precipitation in any given area may be predicted by meteorological modeling techniques or inferred through remote sensing, yet neither method currently has the ability to define the distribution parameters (numbers and sizes) of the precipitating particles.

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20. Abstract - Contd.

This report describes the development of a model that may be used to estimate the parameters of precipitable rain distributions from inputs of liquid-water-content and/or measurements of radar reflectivity coupled with standardized cloud physics relationships.

The model is developed from an equation set based on an exponential distribution function. Aircraft-acquired data are used to verify the conformity of rain distributions to exponential shapes. Empirical relationships provided by these data verified the existence of a nondimensional predictable entity (ΛD_m = distribution slope times maximum drop size), which provides improved estimates of rain distributions from predicted or measured values of liquid-water-content and radar reflectivity.

Tables listing the variations in the size distributions during three rain situations are given in Appendix A.

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Contents

Illustrations

Tables

A Model for the Estimation of Rain Distributions

1. INTRODUCTION

Although detailed microphysical hydrometeor definitions are not a necessary requirement in the initial development of dynamic models for future application in meteorological forecasting, any effort designed to predict or describe situations in which precipitation is present has to be able to produce realistic facsimiles of hydrometeor type, concentration, and size distribution. This is particularly necessary in forecasting scenarios where a choice has to be made between various systems that have weather-dependent operational efficiencies, such as in aircraft safety, optical guidance (smart weapons), and communications. Thus, it is extremely important, at this time, before our dynamic models reach the point of becoming operational, to develop the methods by which information of this type can be included in future large-scale models so that they may be used as effective forecasting tools.

This report describes the development of a mathematical model or equation set that can reasonably describe the parameters of precipitable liquid hydrometeors for the subsequent inclusion in more comprehensive, large-scale models. The effort encompassed the analysis of aircraft distribution data for the empirical determination of mathematical relationships to describe the sizes and shapes of

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hydrometeor populations and the documentation of the variabilities of rain distribution parameters that may be used to establish probabilities of occurrences.

2. DERIVATION OF EQUATIONS

It has been demonstrated by Marshall and Palmer,[1] Marshall and Gunn,[2] Imai et al,[3] Gunn and Marshall,[4] Ohtake and Henmi[5] and others that the size distribution properties of raindrops, snowflakes, and ice crystals of precipitable size can be reasonably described by a distribution function of exponential type. This distribution function specifies that the number concentration of the hydrometeor particles will decrease with increasing diameter (or equivalent-melted diameter) in the manner

$$N = N_0 e^{-\Lambda D} \quad , \quad (d \leq D \leq D_m) \quad , \quad \text{No. m}^{-3}\ \text{mm}^{-1} \quad , \tag{1}$$

where N_0 is the number per cubic meter per millimeter bandwidth at the zero intercept of the semi-logarithmic, number-density plot, Λ is number per millimeter bandwidth and is the slope of the number-density distribution, and D is the drop diameter in millimeters.

The equation, as applied herein, is presumed to be descriptive only between the truncation limits $D = d$ (a minimum diameter) and $D = D_m$ (a maximum diameter). This subject of the double truncation of an exponential distribution function has been previously discussed by Sekhon and Srirastava.[6]

The total number of hydrometeors (N_T) in a population described by Eq. (1) is

$$N_T = \int_d^{D_m} N\, dD \quad \text{No. m}^{-3} \tag{2}$$

1. Marshall, J.S., and Palmer, W.McK. (1948) The distribution of raindrops with size, J. Meteorol. 5:165-166.
2. Marshall, J.S., and Gunn, K.L.S. (1952) Measurement of snow parameters by radar, J. Meteorol. 9:322.
3. Imai, I., Fujiwara, M., Ichimura, I., and Toyama, Y. (1955) Radar reflectivity of falling snow, Pap. in Meteorol. and Geophys. (Japan) 6:130-139.
4. Gunn, K.L.S., and Marshall, J.S. (1958) The distribution with size of aggregate snowflakes, J. Meteorol. 15:452(479).
5. Ohtake, T., and Henmi, T. (1970) Radar reflectivity of aggregated snowflakes, Preprints of papers presented at the 14th Radar Meteorology Conference, Tucson, Arizona, 17-20 November 1970, pp. 209-211.
6. Sekhon, R.S., and Srivastava, R.C. (1970) Snow size spectra and radar reflectivity, J. Atmos. Sci. 27:299-307.

or

$$N_T = \frac{N_0 r_N}{\Lambda} \quad \text{No. } m^{-3} \quad , \tag{3}$$

where r_N is a "*truncation ratio*" specified by

$$r_N = \frac{\int_d^{D_m} N \, dD}{\int_0^{\infty} N \, dD} \tag{4}$$

which becomes

$$r_N = e^{-d\Lambda} - e^{-D_m \Lambda} \quad . \tag{5}$$

The liquid-water-content or mass (M) of the hydrometeor populations described by Eq. (1) is distributed with diameter as a function of the third moment of Eq. (1), or as

$$M_D = \frac{\pi}{6} \times 10^{-3} \rho_\omega N_0 D^3 e^{-\Lambda D} \text{ g m}^{-3} \text{ mm}^{-1} \quad , \tag{6}$$

where $d < D < D_m$ and ρ_ω is the density of liquid water in g cm^{-3}.

The total liquid-water-content of the population is

$$M = \int_d^{D_m} M_D \, dD \text{ g m}^{-3} \tag{7}$$

which, from Eq. (6) and integration, yields

$$M = \frac{\pi \times 10^{-3} \rho_\omega N_0 \Gamma(4) r_M}{6\Lambda^4} \text{ g m}^{-3} \quad , \tag{8}$$

where $\Gamma(4)$ is the gamma function of 4 and r_M is a truncation ratio for liquid-water-content given by

$$r_M = \frac{\int_d^{D_m} M_D \, dD}{\int_0^{\infty} M_D \, dD} \tag{9}$$

or

$$r_M = \frac{1}{6} \left\{ e^{-d\Lambda} \left[(d\Lambda)^3 + 3(d\Lambda)^2 + 6\, d\Lambda + 6\right] - e^{-D_m\Lambda} \left[(D_m\Lambda)^3 + 3(D_m\Lambda)^2 + 6D_m\Lambda + 6\right] \right\} \quad . \tag{10}$$

The distributed values of the radar reflectivity factor (Z) for the hydrometeor populations described by Eq. (1) are specified by

$$Z_D = N_0 \, D^6 \, e^{-\Lambda D} \quad , \quad (d < D < D_m) \quad , \quad mm^6 \, m^{-3} \, mm^{-1} \quad . \tag{11}$$

The total value of the radar reflectivity factor, for the entire population of hydrometeors, is

$$Z = \int_d^{D_m} Z_D \, dD \; mm^6 \, m^{-3} \tag{12}$$

or, from Eq. (11) on integration,

$$Z = \frac{N_0 \, \Gamma(7) \, r_Z}{\Lambda^7} \; mm^6 \, m^{-3} \quad , \tag{13}$$

where $\Gamma(7)$ is the gamma function of 7 and r_Z is the truncation ratio for the radar reflectivity factor as defined by

$$r_Z = \frac{\int_d^{D_m} Z_D \, dD}{\int_0^{\infty} Z_D \, dD} \quad , \tag{14}$$

and Z_D becomes

$$Z = \frac{1}{720}\Big\{e^{-d\Lambda}[(d\Lambda)^6 + 6(d\Lambda)^5 + 30(d\Lambda)^4 + 120(d\Lambda)^3 + 360(d\Lambda)^2 + 720\,d\Lambda + 720]$$

$$- e^{-D_m\Lambda}[(D_m\Lambda)^6 + 6(D_m\Lambda)^5 + 30(D_m\Lambda)^4 + 120(D_m\Lambda)^3$$

$$+ 360(D_m\Lambda)^2 + 720(D_m\Lambda) + 720]\Big\} \quad . \qquad (15)$$

The so-called "diameters" of the M_D and Z_D distributions are "characteristic parameters" of the hydrometeor populations. These diameters, which specify the maximum-value points of liquid-water-content and radar reflectivity factor, are given respectively by

$$D'_M = 3/\Lambda \text{ mm} \qquad (16)$$

and

$$D'_Z = 6/\Lambda \text{ mm} \quad . \qquad (17)$$

An additional characteristic parameter of the M_D distribution that is conventionally used and referenced is the median volume diameter (D_0). This diameter satisfies the integral relation

$$\int_d^{D_0} M_D\, dD = \int_{D_0}^{D_m} M_D\, dD \quad , \qquad (18)$$

which, if the integration is performed using Eq. (6), and if all Λ terms are included on the right, yields

$$D_0 = \frac{1}{\Lambda}\ln\left\{\frac{2[(D_0\Lambda)^3 + 3(D_0\Lambda)^2 + 6D_0\Lambda + 6]}{e^{-d\Lambda}[(d\Lambda)^3 + 3(d\Lambda)^2 + 6d\Lambda + 6] + e^{-D_m\Lambda}[(D_m\Lambda)^3 + 3(D_m\Lambda)^2 + 6\,D_m\Lambda + 6]}\right\}\ mm \quad . \qquad (19)$$

It is seen that D_0 is nonseparable in this equation. However, the equation can be readily solved by trial-and-error once information about d, D_m, and Λ is available.

The parameter N_0 may be eliminated between Eqs. (8) and (13) to provide an expression for the "exponential slope" of the distribution function of Eq. (1). Thus, after evaluation of ρ_w, $\Gamma(4)$, and $\Gamma(7)$

$$\Lambda = 61.2 \left(\frac{M\, r_Z}{Z\, r_M}\right)^{1/3} \mathrm{mm}^{-1} \quad . \tag{20}$$

We can also eliminate the parameter Λ between Eqs. (8) and (13) to obtain an expression for N_0 should we wish.

Equations (1) through (20) constitute a descriptive equation set, or model, that, with several assumptions as will be discussed here, can be solved in closed form.

The distribution equations, Eqs. (1), (6), and (11), for a truncated model are identical to those for a nontruncated model except for the recognition that the truncated equations have significance only between the diameter limits $D = d$ to $D = D_m$.

The totals equations, Eqs. (3), (8), and (13), differ from those of a nontruncated model in that the former contain the truncation ratios, r_N, r_M, and r_Z, as defined by Eqs. (5), (10), and (15). These truncation ratios are seen to be functions of d, D_m, and Λ.

The equations presented in this section, as previously mentioned, are pertinent to precipitable liquid hydrometeors only, namely rain or the resulting melted drops from snow/ice particles. This particular investigation, henceforth, will only be concerned with rain. It is planned to continue these studies into the snow/ice region.

3. DATA ANALYSIS

The LYC archives were searched to find the best rain situation to analyze in order to investigate the validity of the preceding equation set. The case selected was one of widespread rain that was sampled by a MC-130E instrumented aircraft near Talladega, Alabama on 23 February 1977, where measurements of precipitation were taken continuously for 24 min, from 2222 to 2246 GMT. Data used in this analysis were from a PMS 1-D[7] precipitation probe that counted raindrops from 0.2- to 4.65-mm diameter and classified them by size in 15 channels of

7. Knollenberg, R.G. (1970) The optical array: an alternative to scattering or extinction for airborne particle size determination, J. Appl. Meteor. 9 (No. 1):86-103.

~ 0.3-mm width. The measurements were taken at a 1-sec time resolution. This particular case had data recorded in each of the 1440 1-second samples.

This rain situation has been previously analyzed using a nondimensional technique (Plank, Berthel, and Delgado)[8] to test the exponential distribution assumption for rain. That investigation determined that distributions of liquid hydrometeors could be described by exponential functions with the distributions becoming more exponential in form as averaging time increased.

Similar findings are illustrated in Figure 1. The number-density distribution plots for the initial 1, 5, 10, 50, 100, and 500 sec of the sampling period show the number of drops (normalized to a cubic meter per millimeter bandwidth) in each PMS 1-D channel plotted vs the midpoint diameter of each class. The solid lines are "best fit" lines derived from least-squares regression analysis. The dashed lines are slopes calculated using Eq. (20). (Determination of the slope in this manner is discussed in more detail later in this section.) The points in the first plot are from basic 1-sec data. The others are mean values found by summing the results of each channel for the basic period and dividing by the averaging time interval. These plots demonstrate that the number-density distributions do reasonably conform to exponential shape and that the agreement with the exponential becomes better as averaging time increases.

Data supplied by the 1-D instrument provides direct information on four basic parameters of that portion of the hydrometeor distribution that is confined within the instrument's measuring limits; the total number of drops (N_T), largest diameter drop size (D_m), liquid-water-content (M), and equivalent radar reflectivity (Z).

The number of drops contained in a cubic meter is determined from knowledge of the sampling area (m^2) and speed of the aircraft (m/s), which gives sampling volume (m^3), and number of drops actually counted. Adjustment of sampling volume to one cubic meter allows the calculation of N_T. Figure 2 is a plot of the mean values of the total number of drops of the 1440 distributions over different averaging intervals. Values of the [illegible], maximums, and the spread of one standard deviation from the [illegible] are [illegible] indicated.

The D_m [illegible] of the distributions can be determined approximately, within ~ 0.1[illegible], by using the [illegible] of the channel in which the largest drop was recorded. Figure 3 shows the means, minimums, maximums, and standard deviations of D_m over different averaging intervals.

The parameter most readily determined from the hydrometeor distribution is M, the mass concentration of liquid-water content. Knowledge of the class mid-diameters

8. Plank, V.G., Berthel, R.O., and Delgado, L.V. (1980) The shape of raindrop spectra for different situations and averaging periods, J. Rech. Atmos. 14:301-309, AFGL-TR-81-0008, AD A094877.

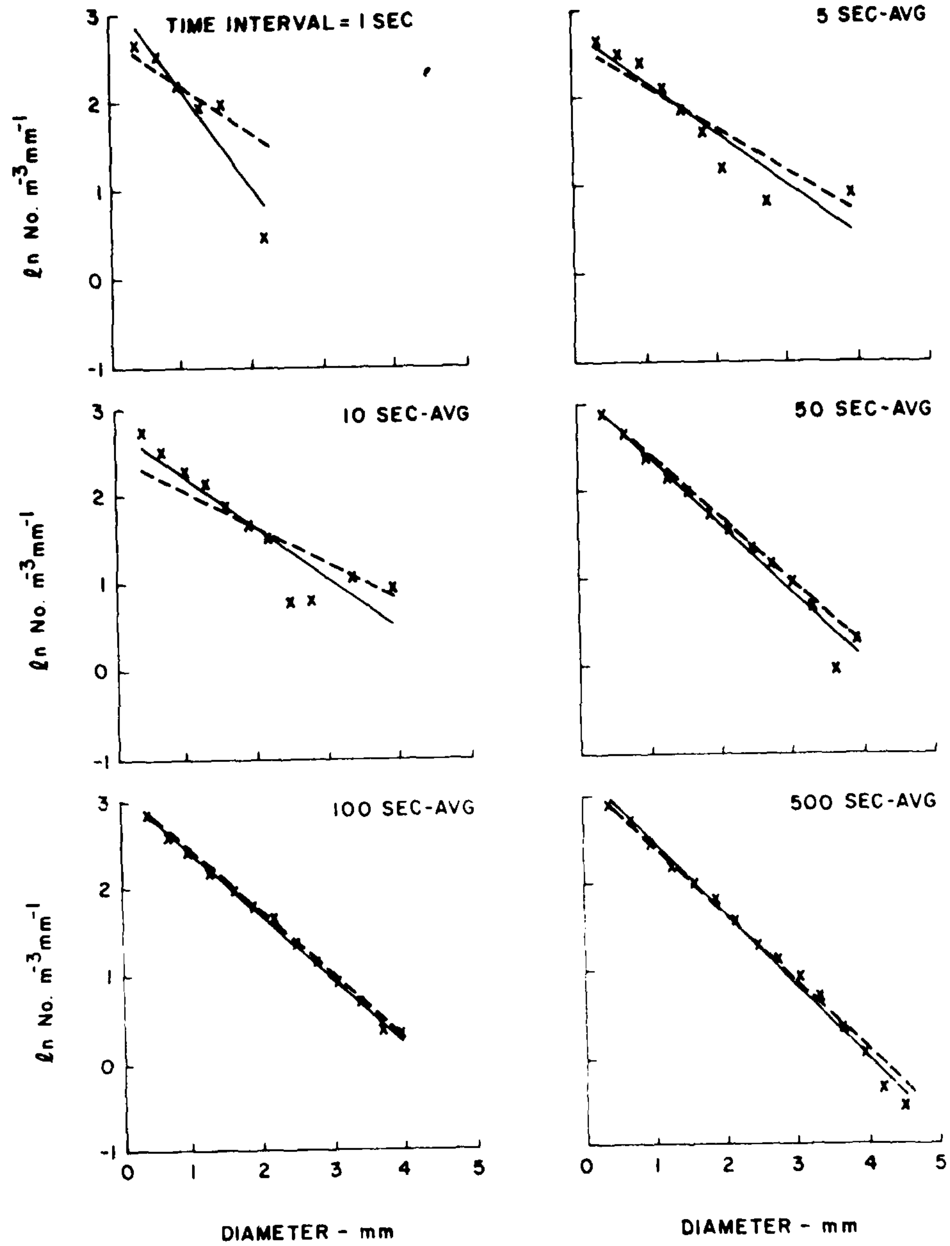

Figure 1. Number Density Distributions for the Initial 1, 5, 10, 50, 100, and 500 Sec of the Rain Situation on 23 February 1977

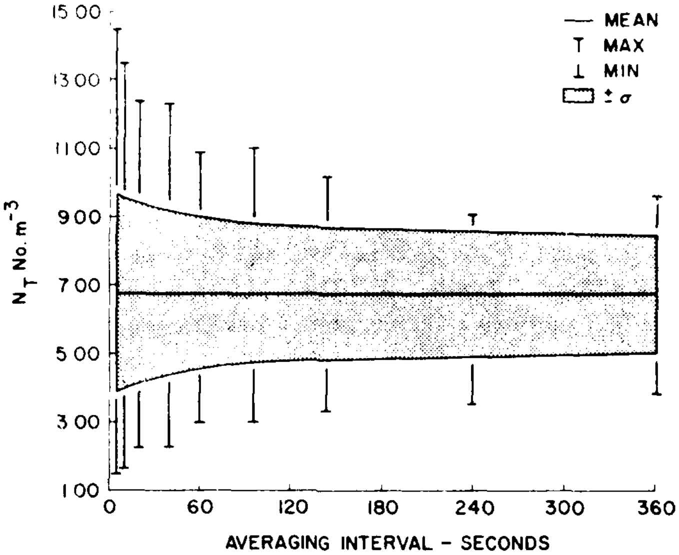

Figure 2. Plot of the Mean, Minimum, and Maximum Values of N_T vs Averaging Time on 23 February 1977

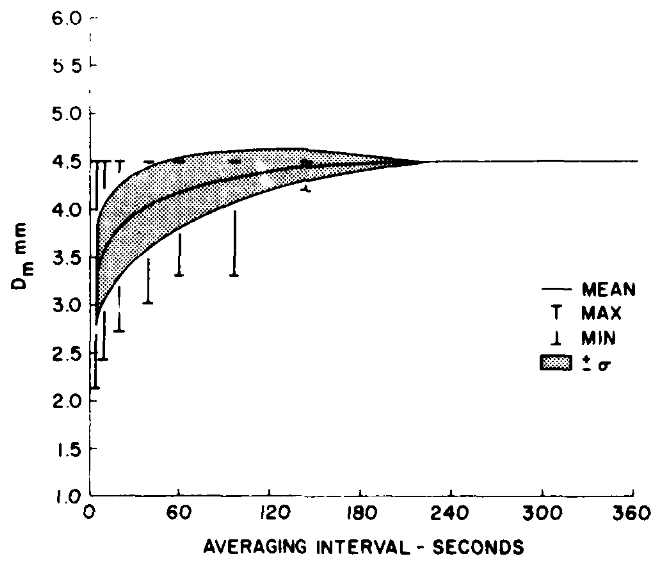

Figure 3. Plot of the Mean, Minimum, and Maximum Values of D_m vs Averaging Time on 23 February 1977

and the number of drops per cubic meter allows this value to be calculated, assuming each drops to be spherical, as

$$M_i = \frac{\pi}{6} \times 10^{-3} \rho_w D_i^3 N_i \quad g\ m^{-3} \quad , \tag{21}$$

where "i" is the class designation, ρ_w is, once again, the density of liquid water ($g\ cm^{-3}$), D_i is the middiameter of class "i", and N_i is the number of drops per cubic meter in the class.

The total M of a particular distribution is found by summing the contents of each class as

$$M = \frac{\pi}{6} \times 10^{-3} \rho_w \sum_{i=1}^{i=15} D_i^3 N \quad g\ m^{-3} \quad . \tag{22}$$

The equivalent radar values can be calculated in similar fashion as

$$Z_i = D_i^6 N_i \quad mm^6\ m^{-3} \tag{23}$$

and

$$Z = \sum_{i=1}^{i=15} D_i^6 N_i \quad mm^6\ m^{-3} \quad . \tag{24}$$

The means, minimums, maximums, and standard deviations for M and Z are plotted in Figures 4 and 5 for various averaging periods.

Of these four parameters, D_m displays the least amount of variability (Table A3) within this specific case example. However, all will differ widely in different rain situations. Thus, none can be considered a predictable quantity.

Examination of the equations in Section 2 reveal other parameters; N_0, D_0, and Λ and the truncation ratios r_N, r_M, and r_Z, that can be termed "derived variables" in that they are derived from calculations using the data from the PMS 1-D and the assumption of exponential shape. The single, most-identifying feature of any exponential distribution is Λ, as it is an integral part of all the equations cited in Section 2. This, the slope of the number-density distribution, can be determined through knowledge of M and Z and utilization of Eq. (20) as previously mentioned. The slope can also be derived by using N_T with M or Z by eliminating

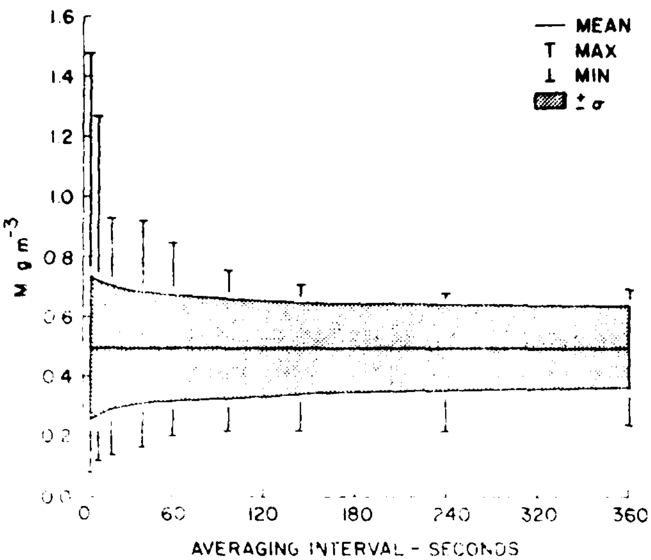

Figure 4. Plot of the Mean, Minimum, and Maximum Values of M vs Averaging Time on 23 February 1977

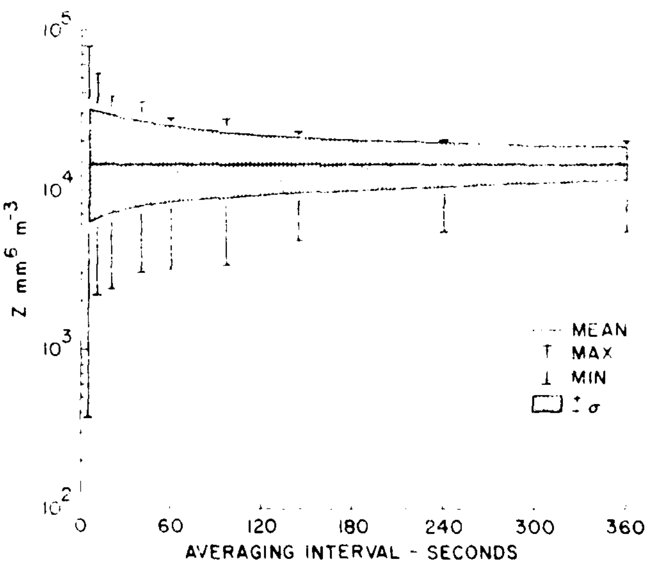

Figure 5. Plot of the Mean, Minimum, and Maximum Values of Z vs Averaging Time on 23 February 1977

N_0 and equating Eqs. (1) and (8) or Eqs. (1) and (13). Since this investigation is primarily concerned with the prediction of realistic rain distributions from forecasts of dynamic models, we chose to use the M and Z as these parameters are the more-likely candidates for prediction modeling (this subject will be discussed further in Section 4).

The dashed lines in Figure 1 show the Λ's that were calculated using Eq. (20) for each of the distributions. This method of determining Λ assumes a full distribution or, in other words, a representative number of drops in each class that will fulfill the requirements imposed by the M and Z parameters. The least-squares method, which is dependent on distributed numbers, does not take into account the dependency of M on diameter to the third power [Eq. (21)] and Z on diameter to the sixth power [Eq. (23)]. The small averaging intervals represent extremely small sampling volumes ($<\sim 1\ m^3$) and some of the 1-D classes are deficient or devoid of drops (Plank and Berthel).[9] Therefore, it is not surprising that the two methods, Eq. (20) and the least squares, differ at the small sampling intervals but tend to agree more as the averaging period becomes larger. (Similar results are obtained when using N_T in the calculation of Λ.)

Figure 6 shows the means, minimums, maximums, and standard deviations that were calculated using M and Z in Eq. (20) for different averaging periods.

The calculations of Λ in Figure 6 used the experimentally determined values of D_m in solving for r_M and r_Z [Eqs. (10) and (15)]. In any scenario using predicted values of M and Z, D_m will be an unknown quantity. Thus, some judgement or assumption has to be made as to the largest drop size that would most likely be present. When the equations for the truncation ratios of M and Z are considered [Eqs. (10) and (15)], it is apparent that the two unknown values are Λ and D_m since d can be defined as the diameter where a drop is of sufficient size to become precipitable. (A precise definition of d is not always necessary since small changes do not significantly effect M, Z, or the calculated Λ. But, it does have a decided effect in the calculation of the total number of drops because of the negative slope of the exponential number distribution.)

Multiplication of the Λ and D_m parameters forms a nondimensional entity (ΛD_m) and, if d and ΛD_m are assigned values, leaves a single unknown, Λ, in Eqs. (10) and (15). This manipulation now allows Λ to be determined through the solving of Eq. (20) by the trial-and-error method. Figure 7 shows the ΛD_m means, minimums, maximums, and standard deviations for this sample case over different averaging periods.

9. Plank, V.G., and Berthel, R.O. (1982) A descriptive double-truncated exponential model for hydrometeors of precipitable size, Preprints of papers presented at the Conference on Cloud Physics, Chicago, Illinois, 15-18 November 1982, pp. 190-194, AFGL-TR-82-0347, AD A122036.

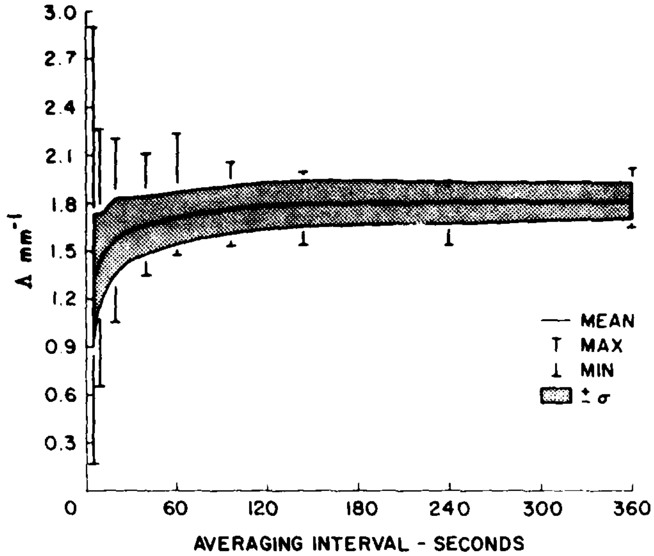

Figure 6. Plot of the Mean, Minimum, and Maximum Values of Λ vs Averaging Time on 23 February 1977

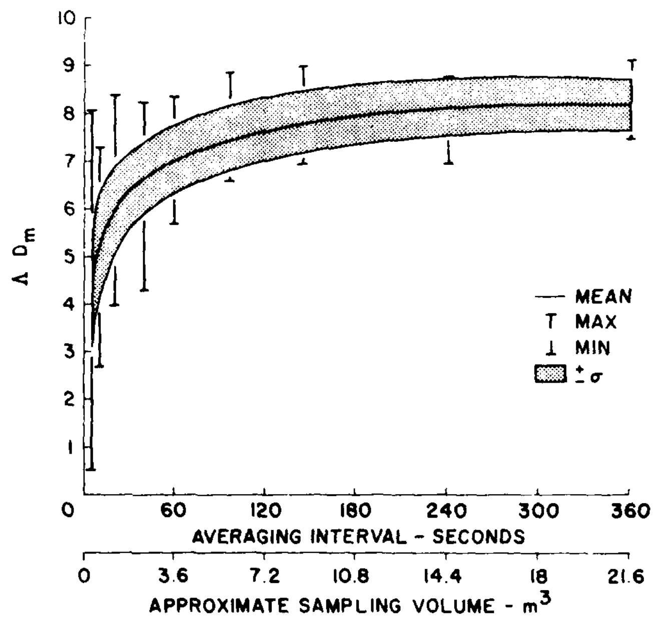

Figure 7. Plot of the Mean, Minimum, and Maximum Values of ΛD_m vs Averaging Time and Sampling Volume on 23 February 1977

All the parameters discussed in this section vary considerably within any specific rain situation with the variance being dependent upon averaging period. These same parameters, with the exception of ΛD_m, can show substantial variations between different rain cases. ΛD_m, although displaying a dependence upon averaging period, tends to have the same approximate value in all rain situations. Thus, it can be used as a predictable quantity.

4. DISCUSSION

Our presumptions about the parameters Λ and D_m were the following. For any single hydrometeor sample, irrespective of spectral type, that is, exponential, bi-modal, etc., it has been demonstrated by Plank, Berthel, and Barnes[10] that

$$M = \kappa \, Z^{.5} \quad g \, m^{-3} \quad , \tag{25}$$

where κ is the so called "kappa factor" that can be evaluated from aircraft data. When this equation is substituted into Eq. (20),

$$\Lambda = 61.2 \left(\frac{\kappa^2 \, r_Z}{M \, r_M} \right)^{1/3} \quad mm^{-1} \quad . \tag{26}$$

For a family of hydrometeor samples, we presumed that an M vs Z relation existed that was of power function form,

$$M = a \, Z^b \quad g \, m^{-3} \tag{27}$$

and that was assumed to be known either from literature information or from regression analyses performed on joint aircraft-radar data. If Eq. (27) is substituted into Eq. (20),

$$\Lambda = 61.2 \, a^{1/3b} \, M^{b-1/3b} \left(\frac{r_Z}{r_M} \right)^{1/3} \quad mm^{-1} \quad . \tag{28}$$

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10. Plank, V.G., Berthel, R.O., and Barnes, Jr., A.A. (1980) An improved method for obtaining water content values of ice hydrometeors from aircraft and radar data, J. Appl. Meteorol. 19:1293-1299, AFGL-TR-81-0011, AD A094328.

The inclusion of Eq. (28) into the equation set for a family of samples insures the consistency of the distribution equations, particularly the totals equations, with the M vs Z relation that is presumed for the family. It also obviates any need to determine Λ by least-squares methods, such as discussed by Smith and Laco.[11]

When we first began using the truncated equations to describe the approximate distribution properties of hydrometeors along trajectory paths of re-entry vehicles, we had virtually no information about the nature of the possible variability of the ΛD_m quantity that appears in the equations for the truncation ratios. Thus, we made the obvious first assumption that this quantity might have a constant value, that is,

$$\Lambda D_m = C \quad . \tag{29}$$

From surface disdrometer data for rain that were acquired at Wallops Island, Virginia (Plank),[12] we deduced that the value of the constant was about 7.5. We also recognized that, for rain containing drops of the breakup size, the upper truncation situation would no longer be governed by Eq. (29) but would be specified by

$$D_m = \textit{breakup diameter} \cong 5 \textit{ mm} \quad . \tag{30}$$

In the fall of 1981, we undertook an investigation of the details of ΛD_m variability and found that for rain, the quantity ΛD_m was primarily dependent on sampling volume and was secondarily dependent on variations of liquid-water-content within the samples. The example of the relatively homogeneous situation of rain that was aircraft sampled on 23 February 1977 (Figure 7) depicts the way that ΛD_m (solid curve) increased with sampling interval or with sampling volume. The shaded envelope on either side of the curve indicates the first standard deviation of the individual ΛD_m values. This scatter is mostly due to the variations of liquid-water-content within the samples.

Figure 7 indicates that the ΛD_m values increase with sampling volume and that they appear to attain a asymptotic value of about 8.2 for a sampling volume

11. Smith, Jr., P.L., and Laco, C.P. (1978) Techniques for fitting size distribution functions to observed particle size data, Preprints of papers presented at the 18th Conference on Radar Meteorology, Atlanta, Georgia, 28-31 March 1978, pp. 129-133.

12. Plank, V.G. (1977) Hydrometeor data and analytical-theoretical investigations pertaining to the SAMS Missile Flights of the 1972-73 season at Wallops Island, Virginia, Environmental Research Papers No. 603, AFGL/SAMS Report No. 5, AFGL-TR-77-0149, AD A051192, 239 pp.

somewhat in excess of $10 m^3$. This volume, it should be noted, is the volume of a representative atmospheric sample for the Alabama rain situation. Any sample of appreciably smaller size is a nonrepresentative sample.

Figure 8 compares the ΛD_m values that were obtained on 23 February 1977, with those from two other rain situations sampled by the MC-130E, one near the Kwajalein atoll on 4 July 1978, and the other near Hanscom Air Force Base on 15 August 1979. In this figure, the ΛD_m parameters are plotted against sampling volume. The latter two cases were of much shorter duration thus, less sampling volume.

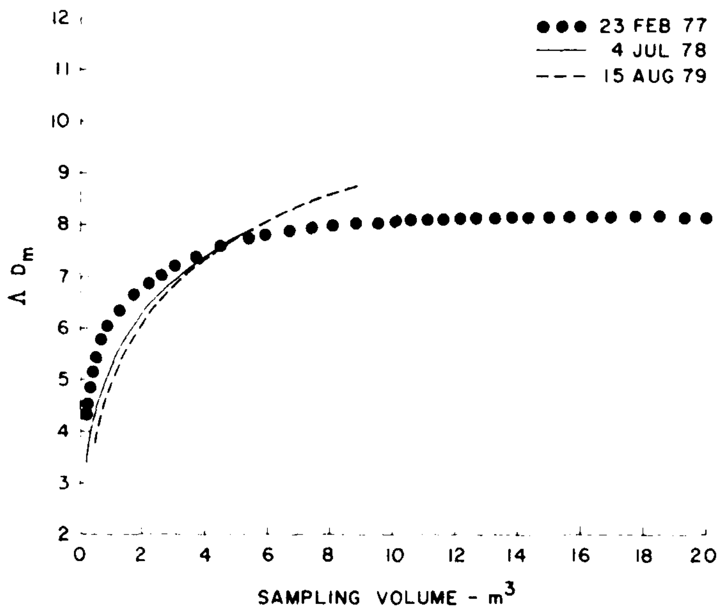

Figure 8. Plot of ΛD_m vs Sampling Volume for Three Rain Situations

Although these latter cases display considerably more variability than 23 February, all three curves show small ΛD_m values at small sampling volumes and all increase markedly up to a volume of $\sim 6\ m^3$. It appears that an asymptotic value is reached at $\sim 10\ m^3$.

The finding that a representative atmospheric sample for rain is of the order of 10 m^3 corresponds with the comments and equations of Joss and Waldvogel[13] in that, for surface rain with rates from 1 to 10 mm hr^{-1}, about 6 to 19 m^3 sampling volume is required to determine radar Z values from size distribution data with a 0.95 probability of 90 percent accuracy. Moreover, Plank, Berthel, and Delgado[12] have shown that flight durations of some 50 to 100 sec (5 to 10 m^3 volume) are required to obtain stable, representative size distribution information for rain.

5. COMPARISONS OF TRUNCATED AND NONTRUNCATED DISTRIBUTIONS OF EXPONENTIAL TYPE

To illustrate the differences between truncated exponential distributions and nontruncated distributions, we have assumed the M vs Z relation

$$M = 0.00314\ Z^{0.576} \qquad g\ m^{-3} \quad , \tag{31}$$

which corresponds to the "widespread rain" situations of Joss, Thams, and Waldvogel[14] and which we have found to provide good descriptions for such rains at Wallops Island and Kwajalein.

From this assumed M vs Z relation containing a total liquid-water-content value of 0.2 g m^{-3}, the equation set described previously herein was solved for the case of nontruncation. In such case, the truncation ratios r_N and r_M and r_Z all have the value unity. The distribution curves for number concentration N, for liquid-water-content M and for radar reflectivity factor Z are shown in Figure 9. They are the solid curves.

For comparison, we considered two other situations. First, was a situation of representative atmospheric sampling for which, (in the Alabama case) ΛD_m = 8.2, r_N = 0.696, r_M = 0.956, and r_Z = 0.688. The equation set was solved for these values for d = 0.2 mm and for a total liquid-water-content value of 0.2 g m^{-3}, as before. The distribution curves for this situation are also shown in Figure 9. They are the dashed curves.

We next considered a situation of typical aircraft sampling with PMS 1-D instruments. We chose a 5-sec sampling interval that corresponds to about 500 m

13. Joss, J., and Waldvogel, A. (1969) Raindrop size distribution and sampling size distribution and sampling size errors, J. Atmos. Sci. 26:566-569.

14. Joss, J., Thams, J.C., and Waldvogel, A. (1968) The variation of raindrop size distributions at Locarno, Proc. Internatl. Conf. on Cloud Physics, Toronto, Amer. Meteorol. Soc. Boston, p. 369.

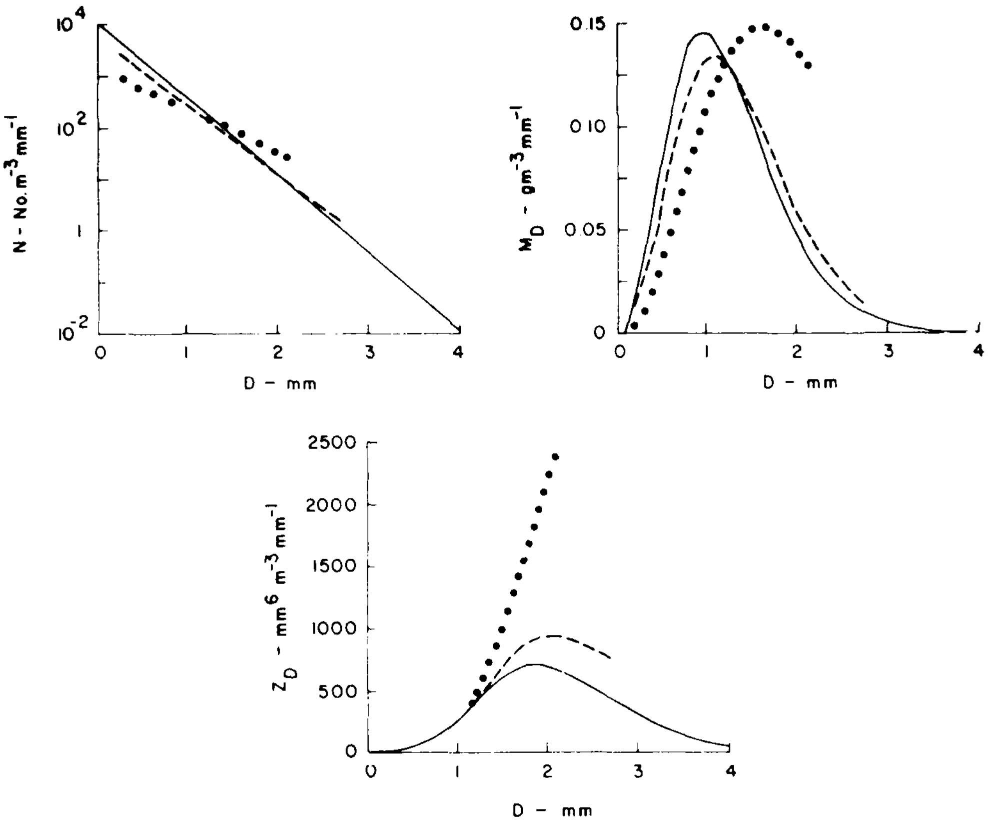

Figure 9. The Distributed Values of N, M, and Z for a Nontruncated Situation (Solid Line) and Those Truncated with $D_m\Lambda$ = 4.5 (Dotted Line) and $D_m\Lambda$ = 8.2 (Dashed Line). In all cases, M = 0.2 g m^{-3} and Z = 1356 $mm^6 m^{-3}$

of flight path distance at sampling airspeeds. The sampling volume for this interval is about 0.3 m^3, which is considerably smaller than a representative sampling. With reference to Figure 7, the $D_m\Lambda$ value for this sampling volume is about 4.5, the r_N, r_M, and r_Z are about 0.740, 0.639, and 0.192, respectively. The equation set was solved for these values and the results are presented in Figure 9 (dotted curves).

It is seen that the differences between the three solutions are considerable. There are no differences in the M values, since these were assumed equal. There are also no differences in the Z values, because of Eq. (31). However, there are major differences in the Λ, D_m, and N_T values that are listed in Table 1.

Table 1. Comparison of the Λ, D_m, and N_T from a Nontruncated Distribution and Two Truncated Situations with Different Sampling Volumes. ($M = 0.2$ g m^{-3}, $Z = 1355.6$ mm^6 m^{-3} in all cases)

	Λ mm^{-1}	D_m mm	N_T No. m^{3}
Nontruncated $\Lambda D_m = \infty$	3.23	∞	2150
Sampling Volume 10 m^3 $\Lambda D_m = 8.2$	2.90	2.76	1130
Sampling Volume 0.3 m^3 $\Lambda D_m = 4.5$	1.88	2.13	550

6. SUMMARY

In this report we have demonstrated the conformity of rain distributions to exponential shape with the conformity being dependent upon sampling volume. We have also presented a set of equations or model based on the exponential distribution function that may be utilized for estimating the parameters of rain distributions. From our investigation of aircraft-acquired measurements, we have developed a new parameterization entity (ΛD_m) that appears to be predictable based on sampling volume.

In any scenario where distributions are to be estimated, some assumption or measurement has to be made in order to define the amount of precipitable water in a given volume of air. We chose to use M and Z as the definable quantities in our model since M should be a common output from any large-scale prediction model and Z can be defined by using existing M vs Z relations for rain. Conversely, definition of Z can be made by remote sensing radar and evaluation of M then determined through these same relationships. Introduction of M and Z into this model, along with a specified sampling volume that dictates the ΛD_m value (Figure 8), will produce reasonable rain number and size information.

The number and sizes of raindrops vary considerably both within a specific situation and between situations. As examples, the variations in distribution parameters for the three cases considered in this study are presented in Appendix A.

This model, or set of equations, used in conjunction with actual or model output values of M and/or Z provides raindrop size distributions. These distributions are needed for theoretical calculations of electromagnetic rain attenuation and for studies of rain erosion on hypersonic vehicles.

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Appendix A

Variabilities in Distribution Parameters for Three Situations

The tables (Tables A1 through A18) presented in this section demonstrate the variabilities in N_T, D_m, M, Z, Λ, and ΛD_m that existed in the three situations sampled in this investigation. They are included to provide an insight as to the possible scatter that may exist in these parameters under differing conditions.

N_T and D_m values are directly from the PMS 1-D measurements. M and Z are calculated from these measurements as explained in Section 3. The Λ values were derived using Eq. (20) and, of course, the ΛD_m quantities are the products of these two parameters.

There is a table for each of the parameters listed for each of the three situations. The tables are divided into subsets according to averaging time intervals. The left side of the heading on each subset lists the averaging time in seconds, the number of averaged points in that particular analysis, the number of points where there were no data on the 1-D record or where Eq. (20) could not be solved using the particular M, Z, and D_m values, the total number of 1-sec 1-D points sampled, and the approximate sampling volume. The right side lists the mean, minimum, and maximum values of that particular number of averaged points and the standard deviation of the set.

The tabulation below each heading ranks the number and percentage of averaged points in percentile classes relative to the mean value. For example, in the first subset of Table A2 the averaging time was 5 sec, there were 288 averaged

points and since all the 1-sec records contained data, the total number of points sampled were 1440. Of the averaged points, 44 or ~ 15 percent of the 288 were within 10 percent of the mean value. Four points or ~ 1 percent of the averaged points were larger than 100 percent from the mean.

Table A1. Variability in N_T on 23 February 1977
(N_T = No. m^{-3}, sampling volume = m^3)

AVERAGE TIME	5	MEAN	676.3
No. OF POINTS	288	MIN	151.4
No. NO DATA	0	MAX	1448
POINTS SAMPLED	1440	σ	289
SAMPLING VOLUME	~0.37		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	4	1.3
90 - 100	4	1.3
80 - 90	8	2.7
70 - 80	14	4.8
60 - 70	16	5.5
50 - 60	27	9.3
40 - 50	37	12.8
30 - 40	38	13.1
20 - 30	48	16.6
10 - 20	48	16.6
0 - 10	44	15.2

AVERAGE TIME	10	MEAN	676.3
No. OF POINTS	144	MIN	166.7
No. NO DATA	0	MAX	1349
POINTS SAMPLED	1440	σ	279
SAMPLING VOLUME	~0.68		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	3	2
80 - 90	3	2
70 - 80	5	3.4
60 - 70	8	5.5
50 - 60	18	12.5
40 - 50	18	12.5
30 - 40	22	15.2
20 - 30	23	15.9
10 - 20	21	14.5
0 - 10	25	17.3

AVERAGE TIME	20	MEAN	676.3
No. OF POINTS	72	MIN	227.5
No. NO DATA	0	MAX	1239
POINTS SAMPLED	1440	σ	263
SAMPLING VOLUME	~1.3		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	2	2.7
70 - 80	2	2.7
60 - 70	4	5.5
50 - 60	8	11.1
40 - 50	10	13.8
30 - 40	11	15.2
20 - 30	13	18
10 - 20	9	12.5
0 - 10	13	18

AVERAGE TIME	40	MEAN	676.3
No. OF POINTS	36	MIN	230.4
No. NO DATA	0	MAX	1232
POINTS SAMPLED	1440	σ	249
SAMPLING VOLUME	~2.4		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	1	2.7
70 - 80	0	0
60 - 70	2	5.5
50 - 60	5	13.8
40 - 50	4	11.1
30 - 40	6	16.6
20 - 30	8	22.2
10 - 20	7	19.4
0 - 10	4	11.1

AVERAGE TIME	60	MEAN	676.3
No. OF POINTS	24	MIN	301.2
No. NO DATA	0	MAX	1091
POINTS SAMPLED	1440	σ	235
SAMPLING VOLUME	~3.4		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	1	4.1
50 - 60	3	12.5
40 - 50	4	16.6
30 - 40	3	12.5
20 - 30	4	16.6
10 - 20	4	16.6
0 - 10	5	20.8

AVERAGE TIME	96	MEAN	676.3
No. OF POINTS	15	MIN	300.9
No. NO DATA	0	MAX	1103
POINTS SAMPLED	1440	σ	214
SAMPLING VOLUME	~5.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	1	6.6
50 - 60	1	6.6
40 - 50	2	13.3
30 - 40	2	13.3
20 - 30	1	6.6
10 - 20	3	20
0 - 10	5	33.3

Table A2. Variability in D_m on 23 February 1977
(D_m [illegible] mm, sampling volume [illegible] m^3)

AVERAGE [illegible]	[illegible]	MEAN	[illegible]	[illegible]	[illegible]
NO. OF POINTS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
NO. NO DATA	0	[illegible]	[illegible]	0	[illegible]
POINTS SAMPLED	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLING VOLUME	[illegible]		[illegible]	[illegible]	
CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS	CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

AVERAGE [illegible]	[illegible]	MEAN	[illegible]	[illegible]	[illegible]
NO. OF POINTS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
NO. NO DATA	0	[illegible]	[illegible]	[illegible]	[illegible]
POINTS SAMPLED	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLING VOLUME	[illegible]		[illegible]	[illegible]	
CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS	CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

AVERAGE [illegible]	[illegible]	MEAN	[illegible]	[illegible]	[illegible]
NO. OF POINTS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
NO. NO DATA	0	[illegible]	[illegible]	[illegible]	[illegible]
POINTS SAMPLED	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
SAMPLING VOLUME	[illegible]		[illegible]	[illegible]	
CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS	CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
100	0	[illegible]	100	[illegible]	[illegible]
[illegible] - 100	0	0	[illegible] - 100	[illegible]	[illegible]
[illegible]	0	0	[illegible]	[illegible]	[illegible]
70 - [illegible]	[illegible]	0	70 - [illegible]	[illegible]	[illegible]
[illegible] - 70	[illegible]	0	[illegible] - 70	[illegible]	[illegible]
[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]
40 - [illegible]	[illegible]	0	40 - [illegible]	0	[illegible]
30 - 40	[illegible]	[illegible]	[illegible] - 40	0	0
20 - 30	0	[illegible]	20 - 30	1	[illegible]
10 - 20	[illegible]	20.[illegible]	10 - 20	0	0
0 - 10	1[illegible]	7[illegible].[illegible]	0 - 10	14	[illegible]

Table A3. Variability in M on 23 February 1977
(M = g m^{-3}, sampling volume = m^3)

AVERAGE TIME	5	MEAN	0.496
No. OF POINTS	288	MIN	0.081
No. NO DATA	0	MAX	1.48
POINTS SAMPLED	1440	σ	0.242
SAMPLING VOLUME	~ 0.37		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	8	2.7
90 - 100	6	2
80 - 90	7	2.4
70 - 80	16	5.5
60 - 70	21	7.2
50 - 60	33	11.4
40 - 50	43	14.9
30 - 40	36	12.5
20 - 30	42	14.5
10 - 20	38	13.1
0 - 10	38	13.1

AVERAGE TIME	10	MEAN	0.496
No. OF POINTS	144	MIN	0.121
No. NO DATA	0	MAX	1.27
POINTS SAMPLED	1440	σ	0.222
SAMPLING VOLUME	~ 0.68		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	1	0.6
90 - 100	1	0.6
80 - 90	4	2.7
70 - 80	9	6.2
60 - 70	8	5.5
50 - 60	18	12.5
40 - 50	23	15.9
30 - 40	22	15.2
20 - 30	19	13.1
10 - 20	16	11.1
0 - 10	23	[illegible]

AVERAGE TIME	20	MEAN	0.496
No. OF POINTS	72	MIN	0.138
No. NO DATA	0	MAX	0.928
POINTS SAMPLED	1440	σ	0.206
SAMPLING VOLUME	~ 1.3		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	2	2.7
70 - 80	2	2.7
60 - 70	6	8.3
50 - 60	8	11.1
40 - 50	14	19.4
30 - 40	11	15.2
20 - 30	10	13.8
10 - 20	11	15.2
0 - 10	8	11.1

AVERAGE TIME	40	MEAN	0.496
No. OF POINTS	36	MIN	0.167
No. NO DATA	0	MAX	0.92[illegible]
POINTS SAMPLED	1440	σ	0.197
SAMPLING VOLUME	~ 2.4		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	1	2.7
70 - 80	0	0
60 - 70	3	8.3
50 - 60	5	13.8
40 - 50	7	19.4
30 - 40	6	16.6
20 - 30	2	5.5
10 - 20	6	16.6
0 - 10	6	16.6

AVERAGE TIME	60	MEAN	0.496
No. OF POINTS	24	MIN	0.202
No. NO DATA	0	MAX	0.85
POINTS SAMPLED	1440	σ	0.187
SAMPLING VOLUME	~ 3.4		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	1	4.1
60 - 70	0	0
50 - 60	5	20.8
40 - 50	4	16.6
30 - 40	3	12.5
20 - 30	3	12.5
10 - 20	4	16.6
0 - 10	4	16.6

AVERAGE TIME	96	MEAN	0.496
No. OF POINTS	15	MIN	0.221
No. NO DATA	0	MAX	0.76
POINTS SAMPLED	1440	σ	0.177
SAMPLING VOLUME	~ [illegible].2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	5	33.3
40 - 50	0	0
30 - 40	2	13.3
20 - 30	2	13.3
10 - 20	3	20
0 - 10	3	20

Table A4. Variability in Z on 23 February 1977
(Z · $mm^6 m^{-3}$, sampling volume = m^3)

AVERAGE TIME	5	MEAN	14622
No. OF POINTS	288	MIN	373.4
No. NO DATA	0	MAX	79208
POINTS SAMPLED	1440	σ	13296
SAMPLING VOLUME	~ 0.37		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	28	9.7
90 - 100	12	4.1
80 - 90	27	9.3
70 - 80	31	10.7
60 - 70	25	8.6
50 - 60	32	11.1
40 - 50	31	10.7
30 - 40	22	7.6
20 - 30	25	8.6
10 - 20	31	10.7
0 - 10	24	8.3

AVERAGE TIME	10	MEAN	14622
No. OF POINTS	144	MIN	2219
No. NO DATA	0	MAX	[illegible]810
POINTS SAMPLED	1440	σ	10376
SAMPLING VOLUME	~ 0.68		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	13	9
90 - 100	2	1.3
80 - 90	11	7.6
70 - 80	16	11.1
60 - 70	14	9.7
50 - 60	16	11.1
40 - 50	11	7.6
30 - 40	15	10.4
20 - 30	11	7.6
10 - 20	15	10.4
0 - 10	20	13.8

AVERAGE TIME	20	MEAN	14622
No. OF POINTS	72	MIN	2404
No. NO DATA	0	MAX	38129
POINTS SAMPLED	1440	σ	8527
SAMPLING VOLUME	~ 1.3		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	6	8.3
90 - 100	1	1.3
80 - 90	6	8.3
70 - 80	6	8.3
60 - 70	5	6.9
50 - 60	7	9.7
40 - 50	7	9.7
30 - 40	3	4.1
20 - 30	12	16.6
10 - 20	8	11.1
0 - 10	11	15.2

AVERAGE TIME	40	MEAN	14622
No. OF POINTS	36	MIN	3091
No. NO DATA	0	MAX	35612
POINTS SAMPLED	1440	σ	7761
SAMPLING VOLUME	~ 2.4		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	1	2.7
90 - 100	0	0
80 - 90	2	5.5
70 - 80	3	8.3
60 - 70	4	11.1
50 - 60	7	19.4
40 - 50	2	5.5
30 - 40	1	2.7
20 - 30	3	8.3
10 - 20	9	25
0 - 10	4	11.1

AVERAGE TIME	60	MEAN	14622
No. OF POINTS	24	MIN	3224
No. NO DATA	0	MAX	28372
POINTS SAMPLED	1440	σ	6859
SAMPLING VOLUME	~ 3.4		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	1	4.1
80 - 90	0	0
70 - 80	3	12.5
60 - 70	0	0
50 - 60	5	20.8
40 - 50	4	16.6
30 - 40	2	8.3
20 - 30	3	12.5
10 - 20	2	8.3
0 - 10	4	16.6

AVERAGE TIME	96	MEAN	14622
No. OF POINTS	15	MIN	5450
No. NO DATA	0	MAX	28021
POINTS SAMPLED	1440	σ	6624
SAMPLING VOLUME	~ 5.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	1	6.6
80 - 90	0	0
70 - 80	1	6.6
60 - 70	1	6.6
50 - 60	1	6.6
40 - 50	3	20
30 - 40	2	13.3
20 - 30	2	13.3
10 - 20	1	6.6
0 - 10	3	20

Table A5. Variability in Λ on 23 February 1977
(Λ = mm^{-1}, sampling volume = m^3)

AVERAGE TIME	5	MEAN	1.33
No. OF POINTS	288	MIN	0.17
No. NO DATA	1	MAX	2.9
POINTS SAMPLED	1439	σ	0.417
SAMPLING VOLUME	~0.37		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	2	0.6
90 - 100	0	0
80 - 90	3	1
70 - 80	5	1.7
60 - 70	6	2
50 - 60	15	5.2
40 - 50	23	7.9
30 - 40	34	11.8
20 - 30	53	18.4
10 - 20	65	22.5
0 - 10	81	28.1

AVERAGE TIME	10	MEAN	1.46
No. OF POINTS	144	MIN	0.653
No. NO DATA	0	MAX	2.26
POINTS SAMPLED	1440	σ	0.274
SAMPLING VOLUME	~0.68		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	2	1.3
40 - 50	6	4.1
30 - 40	8	5.5
20 - 30	41	28.4
10 - 20	37	25.6
0 - 10	50	34.7

AVERAGE TIME	20	MEAN	1.59
No. OF POINTS	72	MIN	1.06
No. NO DATA	0	MAX	2.2
POINTS SAMPLED	3600	σ	0.247
SAMPLING VOLUME	~1.3		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	[illegible]	6.9
20 - 30	9	12.5
10 - 20	25	34.7
0 - 10	33	[illegible]

AVERAGE TIME	40	MEAN	1.67
No. OF POINTS	36	MIN	1.35
No. NO DATA	0	MAX	2.11
POINTS SAMPLED	1440	σ	0.18
SAMPLING VOLUME	~2.4		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	0	0
20 - 30	2	[illegible]
10 - 20	14	[illegible]
0 - 10	20	[illegible]

AVERAGE TIME	60	MEAN	1.71
No. OF POINTS	24	MIN	1.48
No. NO DATA	0	MAX	2.24
POINTS SAMPLED	1440	σ	[illegible]
SAMPLING VOLUME	~[illegible]		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	1	4.1
20 - 30	0	0
10 - 20	3	12.5
0 - 10	20	83.3

AVERAGE TIME	[illegible]	MEAN	1.7[illegible]
No. OF POINTS	[illegible]	MIN	[illegible]
No. NO DATA	0	MAX	2.0[illegible]
POINTS SAMPLED	1440	σ	[illegible]
SAMPLING VOLUME	~[illegible]		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	0	0
20 - 30	0	0
10 - 20	[illegible]	[illegible]
0 - 10	10	[illegible]

Table A6. Variability in ΔD_m on 23 February 1977
(sampling volume = m^3)

AVERAGE TIME	[illegible]	MEAN	4.33
No. OF POINTS	288	MIN	0.[illegible]
No. NO DATA	1	MAX	8.08
POINTS SAMPLED	14[illegible]	σ	1.22
SAMPLING VOLUME	~ 0.37		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
100	0	0
90 - 100	0	0
80 - 90	[illegible]	1
70 - 80	[illegible]	1
60 - 70	[illegible]	1.7
50 - 60	12	4.1
40 - 50	20	6.9
30 - 40	[illegible]	10.7
20 - 30	63	21.8
10 - 20	72	25.3
0 - 10	77	26.7

AVERAGE TIME	10	MEAN	5.17
No. OF POINTS	144	MIN	2.68
No. NO DATA	0	MAX	7.3
POINTS SAMPLED	1440	σ	1.02
SAMPLING VOLUME	~ 0.68		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	6	4.1
30 - 40	15	10.4
20 - 30	28	19.4
10 - 20	42	29.1
0 - 10	53	36.8

AVERAGE TIME	20	MEAN	6.05
No. OF POINTS	72	MIN	3.99
No. NO DATA	0	MAX	8.37
POINTS SAMPLED	1440	σ	1
SAMPLING VOLUME	~ 1.[illegible]		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	6	8.3
20 - 30	9	12.[illegible]
10 - 20	32	44.4
0 - 10	25	34.7

AVERAGE TIME	40	MEAN	6.68
No. OF POINTS	36	MIN	4.29
No. NO DATA	0	MAX	8.24
POINTS SAMPLED	1440	σ	0.843
SAMPLING VOLUME	~ 2.4		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	1	2.7
20 - 30	5	13.8
10 - 20	7	19.4
0 - 10	23	63.8

AVERAGE TIME	60	MEAN	7.04
No. OF POINTS	24	MIN	5.77
No. NO DATA	0	MAX	8.14
POINTS SAMPLED	1440	σ	0.673
SAMPLING VOLUME	~ 3.4		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	0	0
20 - 30	0	0
10 - 20	8	33.3
0 - 10	16	66.6

AVERAGE TIME	96	MEAN	7.46
No. OF POINTS	15	MIN	6.59
No. NO DATA	0	MAX	8.85
POINTS SAMPLED	1440	σ	0.655
SAMPLING VOLUME	~ [illegible].2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	0	0
20 - 30	0	0
10 - 20	4	26.6
0 - 10	11	73.3

Table A7. Variability in N_T on 4 July 1978
(N_T = No. m^{-3}, sampling volume = m^3)

AVERAGE TIME	[illegible]	MEAN	[illegible]
No. OF POINTS	42	MIN	[illegible].48
No. NO DATA	1	MAX	[illegible]
POINTS SAMPLED	[illegible]	σ	113.7
SAMPLING VOLUME	~0.[illegible]		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	[illegible]	14.2
90 - 100	1	2.[illegible]
80 - 90	[illegible]	11.9
70 - 80	4	9.5
60 - 70	7	16.6
50 - 60	[illegible]	11.9
40 - 50	2	4.7
30 - 40	4	9.5
20 - 30	2	4.7
10 - 20	[illegible]	7.1
0 - 10	2	4.7

AVERAGE TIME	10	MEAN	1[illegible]2.[illegible]
No. OF POINTS	21	MIN	17.[illegible]
No. NO DATA	0	MAX	[illegible]
POINTS SAMPLED	210	σ	104.[illegible]
SAMPLING VOLUME	~0.98		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	3	14.2
90 - 100	1	4.7
80 - 90	2	9.5
70 - 80	2	[illegible]
60 - 70	3	14.2
50 - 60	1	4.7
40 - 50	3	14.2
30 - 40	1	4.7
20 - 30	1	4.7
10 - 20	2	[illegible]
0 - 10	2	9.5

AVERAGE TIME	20	MEAN	156.3
No. OF POINTS	10	MIN	46.1
No. NO DATA	0	MAX	332
POINTS SAMPLED	200	σ	81.9
SAMPLING VOLUME	~1.8		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	1	10
90 - 100	0	0
80 - 90	0	0
70 - 80	1	10
60 - 70	0	0
50 - 60	1	10
40 - 50	1	10
30 - 40	2	20
20 - 30	1	10
10 - 20	3	30
0 - 10	0	0

AVERAGE TIME	40	MEAN	156.[illegible]
No. OF POINTS	[illegible]	MIN	87.1
No. NO DATA	0	MAX	226
POINTS SAMPLED	200	σ	56.[illegible]
SAMPLING VOLUME	~3.4		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	2	40
30 - 40	2	40
20 - 30	0	0
10 - 20	0	0
0 - 10	1	20

AVERAGE TIME	60	MEAN	1[illegible]9.5
No. OF POINTS	[illegible]	MIN	82.
No. NO DATA	0	MAX	214
POINTS SAMPLED	180	σ	[illegible]
SAMPLING VOLUME	~[illegible]		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	[illegible]	[illegible]
30 - 40	1	[illegible]
20 - 30	0	0
10 - 20	1	[illegible]
0 - 10	0	0

Table A8. Variability in D_m on 4 July 1978

(D_m = mm, sampling volume = m^3)

AVERAGE TIME	[illegible]	MEAN	1.8[illegible]
NO. OF POINTS	[illegible]	MIN	0.944
NO. NO DATA	1	MAX	4.211
POINTS SAMPLED	20[illegible]	σ	0.57[illegible]
SAMPLING VOLUME	≈ [illegible]		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
100	[illegible]	2.[illegible]
90 - 100	0	0
80 - 90	[illegible]	0
70 - 80	[illegible]	0
60 - 70	[illegible]	0
50 - 60	[illegible]	0
40 - 50	[illegible]	11.[illegible]
30 - 40	[illegible]	[illegible]
20 - 30	[illegible]	11.[illegible]
10 - 20	[illegible]	23.
0 - 10	[illegible]	[illegible]

AVERAGE TIME	10	MEAN	2.118
NO. OF POINTS	21	MIN	1.241
NO. NO DATA	0	MAX	4.211
POINTS SAMPLED	210	σ	0.638
SAMPLING VOLUME	≈ 0.98		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
100	0	0
90 - 100	1	4.7
80 - 90	[illegible]	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	[illegible]	[illegible]
30 - 40	0	0
20 - 30	[illegible]	2[illegible]
10 - 20	10	47.
0 - 10	[illegible]	14.2

AVERAGE TIME	20	MEAN	2.4[illegible]
NO. OF POINTS	[illegible]	MIN	2.[illegible]
NO. NO DATA	0	MAX	4.211
POINTS SAMPLED	200	σ	0.68[illegible]
SAMPLING VOLUME	≈ [illegible]		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
100	0	0
90 - 100	0	0
80 - 90	[illegible]	0
70 - 80	1	10
60 - 70	[illegible]	0
50 - 60	[illegible]	[illegible]
40 - 50	0	0
30 - 40	[illegible]	10
20 - 30	[illegible]	10
10 - 20	3	30
0 - 10	[illegible]	30

AVERAGE TIME	[illegible]	MEAN	2.7[illegible]
NO. OF POINTS	[illegible]	MIN	2.1[illegible]
NO. NO DATA	0	MAX	4.211
POINTS SAMPLED	200	σ	0.7[illegible]
SAMPLING VOLUME	≈ [illegible]		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
100	[illegible]	[illegible]
90 - 100	0	0
80 - 90	[illegible]	[illegible]
70 - 80	[illegible]	0
60 - 70	[illegible]	[illegible]
50 - 60	[illegible]	[illegible]
30 - 40	0	[illegible]
30 - 40	[illegible]	[illegible]
20 - 30	[illegible]	20
10 - 20	[illegible]	30
0 - 10	[illegible]	20

AVERAGE TIME	[illegible]	MEAN	[illegible].12[illegible]
NO. OF POINTS	[illegible]	MIN	[illegible]
NO. NO DATA	[illegible]	MAX	4.211
POINTS SAMPLED	[illegible]	σ	0.7[illegible]
SAMPLING VOLUME	≈ [illegible]		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
100	[illegible]	[illegible]
90 - 100	[illegible]	0
80 - 90	[illegible]	0
70 - 80	[illegible]	0
60 - 70	[illegible]	0
50 - 60	[illegible]	[illegible]
40 - 50	[illegible]	[illegible]
30 - 40	[illegible]	[illegible]
20 - 30	[illegible]	[illegible]
10 - 20	[illegible]	[illegible]
0 - 10	[illegible]	[illegible]

Table A9. Variability in M on 4 July 1978
($M = g m^{-3}$, sampling volume = m^3)

AVERAGE TIME		MEAN	0.068
No. OF POINTS	42	MIN	7.0E-4
No. NO DATA	1	MAX	0.168
POINTS SAMPLED	20[illegible]	σ	0.051
SAMPLING VOLUME	~ 0.[illegible]1		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
100	5	11.9
90 - 100	[illegible]	11.9
80 - 90	4	9.5
70 - 80	4	9.5
60 - 70	[illegible]	11.9
50 - 60	[illegible]	14.2
40 - 50	2	4.7
30 - 40	2	4.7
20 - 30	2	4.7
10 - 20	5	11.9
0 - 10	1	2.3

AVERAGE TIME	10	MEAN	0.067
No. OF POINTS	21	MIN	0.0032
No. NO DATA	0	MAX	0.142
POINTS SAMPLED	210	σ	0.047
SAMPLING VOLUME	~ 0.98		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	3	14.2
90 - 100	2	9.5
80 - 90	3	14.2
70 - 80	2	9.5
60 - 70	2	9.5
50 - 60	2	9.5
40 - 50	1	4.7
30 - 40	1	4.7
20 - 30	0	0
10 - 20	2	9.5
0 - 10	3	14.2

AVERAGE TIME	20	MEAN	0.068
No. OF POINTS	10	MIN	0.02
No. NO DATA	0	MAX	0.127
POINTS SAMPLED	200	σ	0.037
SAMPLING VOLUME	~ 1.8		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	2	20
70 - 80	1	10
60 - 70	0	0
50 - 60	2	20
40 - 50	1	10
30 - 40	2	20
20 - 30	1	10
10 - 20	0	0
0 - 10	1	10

AVERAGE TIME	40	MEAN	0.068
No. OF POINTS	5	MIN	0.028
No. NO DATA	0	MAX	0.114
POINTS SAMPLED	200	σ	0.029
SAMPLING VOLUME	~ 3.4		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	1	20
50 - 60	1	20
40 - 50	0	0
30 - 40	0	0
20 - 30	2	40
10 - 20	1	20
0 - 10	0	0

AVERAGE TIME	60	MEAN	0.072
No. OF POINTS	3	MIN	0.047
No. NO DATA	0	MAX	0.092
POINTS SAMPLED	180	σ	0.019
SAMPLING VOLUME	~ 4.6		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	1	33.3
20 - 30	1	33.3
10 - 20	0	0
0 - 10	1	33.3

Table A10. Variability in Z on 4 July 1978
(Z = $mm^6 m^{-3}$, sampling volume = m^3)

AVERAGE TIME	5	MEAN	850
No. OF POINTS	42	MIN	0.993
No. NO DATA	1	MAX	17900
POINTS SAMPLED	209	σ	2726
SAMPLING VOLUME	~ 0.51		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	1	2.3
90 - 100	10	23.8
80 - 90	[illegible]	14.2
70 - 80	3	7.1
60 - 70	[illegible]	11.9
50 - 60	1	2.3
40 - 50	2	4.7
30 - 40	[illegible]	11.9
20 - 30	[illegible]	7.1
10 - 20	2	4.7
0 - 10	[illegible]	7.1

AVERAGE TIME	10	MEAN	830
No. OF POINTS	21	MIN	7.13
No. NO DATA	0	MAX	9186
POINTS SAMPLED	210	σ	1897
SAMPLING VOLUME	~ 0.98		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	1	4.7
90 - 100	4	19
80 - 90	2	9.5
70 - 80	4	19
60 - 70	1	4.7
50 - 60	0	0
40 - 50	1	4.7
30 - 40	2	9.5
20 - 30	1	4.7
10 - 20	0	0
0 - 10	[illegible]	23.8

AVERAGE TIME	20	MEAN	874
No. OF POINTS	10	MIN	113
No. NO DATA	0	MAX	4716
POINTS SAMPLED	200	σ	1312
SAMPLING VOLUME	~ 1.8		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	1	10
90 - 100	0	0
80 - 90	2	20
70 - 80	1	10
60 - 70	1	10
50 - 60	2	20
40 - 50	0	0
30 - 40	0	0
20 - 30	0	0
10 - 20	3	30
0 - 10	0	0

AVERAGE TIME	30	MEAN	862
No. OF POINTS	5	MIN	128
No. NO DATA	0	MAX	2740
POINTS SAMPLED	200	σ	87
SAMPLING VOLUME	~ [illegible]		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	1	20
90 - 100	[illegible]	0
80 - 90	1	20
70 - 80	[illegible]	0
60 - 70	1	20
50 - 60	[illegible]	0
40 - 50	1	20
30 - 40	0	0
20 - 30	0	0
10 - 20	0	0
0 - 10	1	20

AVERAGE TIME	60	MEAN	948
No. OF POINTS	3	MIN	456
No. NO DATA	0	MAX	174
POINTS SAMPLED	180	σ	[illegible]
SAMPLING VOLUME	~ 4.6		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	1	33.3
70 - 80	0	0
60 - 70	0	0
50 - 60	1	33.3
40 - 50	0	0
30 - 40	1	33.3
20 - 30	0	0
10 - 20	0	0
0 - 10	0	0

Table A11. Variability in Λ on 4 July 1978
(Λ = mm^{-1}, sampling volume = m^3)

AVERAGE TIME	[illegible]	MEAN	1.7[illegible]
No. OF POINTS	4[illegible]	MIN	0.[illegible]
No. NO DATA	[illegible]	MAX	4.[illegible]
POINTS SAMPLED	201	σ	0.7[illegible]
SAMPLING VOLUME	~ [illegible]		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	1	2.[illegible]
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	4	9.[illegible]
50 - 60	4	9.5
40 - 50	4	9.[illegible]
30 - 40	4	9.[illegible]
20 - 30	4	9.5
10 - 20	10	23.8
0 - 10	2	4.7

AVERAGE TIME	10	MEAN	1.95
No. OF POINTS	21	MIN	0.358
No. NO DATA	3	MAX	3.15
POINTS SAMPLED	207	σ	0.683
SAMPLING VOLUME	~ 0.98		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	1	4.7
70 - 80	0	0
60 - 70	1	4.7
50 - 60	0	0
40 - 50	3	14.2
30 - 40	2	9.5
20 - 30	5	23.8
10 - 20	3	14.2
0 - 10	3	14.2

AVERAGE TIME	20	MEAN	2.12
No. OF POINTS	10	MIN	0.878
No. NO DATA	0	MAX	3.16
POINTS SAMPLED	200	σ	0.631
SAMPLING VOLUME	~ 1.8		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	1	10
40 - 50	1	10
30 - 40	0	0
20 - 30	4	40
10 - 20	1	10
0 - 10	[illegible]	30

AVERAGE TIME	40	MEAN	2.53
No. OF POINTS	5	MIN	1.25
No. NO DATA	0	MAX	3.11
POINTS SAMPLED	200	σ	0.685
SAMPLING VOLUME	~ 3.4		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	1	20
40 - 50	0	0
30 - 40	0	0
20 - 30	1	20
10 - 20	2	40
0 - 10	1	20

AVERAGE TIME	[illegible]	MEAN	2.[illegible]
No. OF POINTS	[illegible]	MIN	1.41
No. NO DATA	0	MAX	3.07
POINTS SAMPLED	180	σ	0.691
SAMPLING VOLUME	~ 4.[illegible]		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	2	66.6
20 - 30	0	0
10 - 20	0	0
0 - 10	1	33.3

Table A12. Variability in [illegible] on 4 July 1978
(sampling volume [illegible])

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	0	0
20 - 30	1	33.3
10 - 20	2	66.[illegible]
0 - 10	0	0

Table A13. Variability in N_T on 15 August 1979
(N_T = No. m^{-3}, sampling volume = m^3)

AVERAGE TIME	5	MEAN	163.1
No. OF POINTS	40	MIN	31.9
No. NO DATA	0	MAX	366.8
POINTS SAMPLED	200	σ	76.5
SAMPLING VOLUME	~ 0.57		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	2	5
90 - 100	2	5
80 - 90	1	2.5
70 - 80	0	0
60 - 70	3	7.5
50 - 60	3	7.5
40 - 50	3	7.5
30 - 40	3	7.5
20 - 30	8	20
10 - 20	9	22.5
0 - 10	6	15

AVERAGE TIME	10	MEAN	163.1
No. OF POINTS	20	MIN	71.5
No. NO DATA	0	MAX	274.2
POINTS SAMPLED	200	σ	59.2
SAMPLING VOLUME	~ 1.1		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	1	5
50 - 60	3	15
40 - 50	3	15
30 - 40	3	15
20 - 30	3	15
10 - 20	3	15
0 - 10	4	20

AVERAGE TIME	20	MEAN	163.1
No. OF POINTS	10	MIN	92.8
No. NO DATA	0	MAX	247.6
POINTS SAMPLED	200	σ	52.8
SAMPLING VOLUME	~ 2.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	1	10
40 - 50	2	20
30 - 40	1	10
20 - 30	3	30
10 - 20	1	10
0 - 10	2	20

AVERAGE TIME	40	MEAN	163.1
No. OF POINTS	5	MIN	146.3
No. NO DATA	0	MAX	180.8
POINTS SAMPLED	200	σ	14.1
SAMPLING VOLUME	~ 4.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	0	0
20 - 30	0	0
10 - 20	2	40
0 - 10	3	60

AVERAGE TIME	60	MEAN	154.7
No. OF POINTS	3	MIN	136.7
No. NO DATA	0	MAX	170
POINTS SAMPLED	180	σ	13.7
SAMPLING VOLUME	~ 6.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	0	0
20 - 30	0	0
10 - 20	1	33.3
0 - 10	2	66.7

Table A14. Variability in D_m on 15 August 1979 (D_m = mm, sampling volume = m^3)

AVERAGE TIME	5	MEAN	1.286
No. OF POINTS	40	MIN	0.647
No. NO DATA	0	MAX	2.132
POINTS SAMPLED	200	σ	0.301
SAMPLING VOLUME	~ 0.57		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	1	2.5
50 - 60	0	0
40 - 50	4	10
30 - 40	0	0
20 - 30	9	22.5
10 - 20	8	20
0 - 10	18	45

AVERAGE TIME	10	MEAN	1.419
No. OF POINTS	20	MIN	0.944
No. NO DATA	0	MAX	2.132
POINTS SAMPLED	200	σ	0.303
SAMPLING VOLUME	~ 1.1		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	1	5
40 - 50	0	0
30 - 40	2	10
20 - 30	3	15
10 - 20	9	45
0 - 10	5	25

AVERAGE TIME	20	MEAN	1.627
No. OF POINTS	10	MIN	1.241
No. NO DATA	0	MAX	2.132
POINTS SAMPLED	200	σ	0.267
SAMPLING VOLUME	~ 2.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	1	10
20 - 30	2	20
10 - 20	3	30
0 - 10	4	40

AVERAGE TIME	40	MEAN	1.776
No. OF POINTS	5	MIN	1.538
No. NO DATA	0	MAX	2.132
POINTS SAMPLED	200	σ	0.222
SAMPLING VOLUME	~ 4.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	0	0
20 - 30	1	20
10 - 20	2	40
0 - 10	2	40

AVERAGE TIME	60	MEAN	1.835
No. OF POINTS	3	MIN	1.538
No. NO DATA	0	MAX	2.132
POINTS SAMPLED	180	σ	0.242
SAMPLING VOLUME	~ 6.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	0	0
20 - 30	0	0
10 - 20	2	66.7
0 - 10	1	33.3

Table A15. Variability in M on 15 August 1979
(M = $g\,m^{-3}$, sampling volume = m^3)

AVERAGE TIME	5	MEAN	0.036
No. OF POINTS	40	MIN	0.003
No. NO DATA	0	MAX	0.128
POINTS SAMPLED	200	σ	0.028
SAMPLING VOLUME	~ 0.57		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	5	12.5
90 - 100	2	5
80 - 90	3	7.5
70 - 80	4	10
60 - 70	4	10
50 - 60	3	7.5
40 - 50	2	5
30 - 40	6	15
20 - 30	1	2.5
10 - 20	6	15
0 - 10	4	10

AVERAGE TIME	10	MEAN	0.036
No. OF POINTS	20	MIN	0.007
No. NO DATA	0	MAX	0.10
POINTS SAMPLED	200	σ	0.024
SAMPLING VOLUME	~ 1.1		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	2	10
90 - 100	0	0
80 - 90	0	0
70 - 80	2	10
60 - 70	2	10
50 - 60	3	15
40 - 50	2	10
30 - 40	2	10
20 - 30	2	10
10 - 20	3	15
0 - 10	2	10

AVERAGE TIME	20	MEAN	0.036
No. OF POINTS	10	MIN	0.014
No. NO DATA	0	MAX	0.073
POINTS SAMPLED	200	σ	0.018
SAMPLING VOLUME	~ 2.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	1	10
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	1	10
50 - 60	1	10
40 - 50	2	20
30 - 40	3	30
20 - 30	0	0
10 - 20	1	10
0 - 10	1	10

AVERAGE TIME	40	MEAN	0.036
No. OF POINTS	5	MIN	0.024
No. NO DATA	0	MAX	0.06
POINTS SAMPLED	200	σ	0.013
SAMPLING VOLUME	~ 4.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	1	20
50 - 60	0	0
40 - 50	0	0
30 - 40	1	20
20 - 30	0	0
10 - 20	2	40
0 - 10	1	20

AVERAGE TIME	60	MEAN	0.036
No. OF POINTS	3	MIN	0.023
No. NO DATA	0	MAX	0.056
POINTS SAMPLED	180	σ	0.015
SAMPLING VOLUME	~ 6.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	1	33.3
40 - 50	0	0
30 - 40	1	33.3
20 - 30	1	33.3
10 - 20	0	0
0 - 10	0	0

Table A16. Variability in Z on 15 August 1979
(Z = $mm^6 m^{-3}$, sampling volume = m^3)

AVERAGE TIME	[illegible]	MEAN	79.4
No. OF POINTS	40	MIN	1.19
No. NO DATA	0	MAX	413.4
POINTS SAMPLED	200	σ	87.8
SAMPLING VOLUME	~ 0.[illegible]7		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	[illegible]	1[illegible]
90 - 100	4	10
80 - 90	[illegible]	20
70 - 80	4	10
60 - 70	2	[illegible]
50 - 60	2	[illegible]
40 - 50	[illegible]	7.5
30 - 40	4	10
20 - 30	2	[illegible]
10 - 20	2	5
0 - 10	[illegible]	7.[illegible]

AVERAGE TIME	10	MEAN	79.4
No. OF POINTS	20	MIN	6.1
No. NO DATA	0	MAX	357.6
POINTS SAMPLED	200	σ	78.8
SAMPLING VOLUME	~ 1.1		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	2	10
90 - 100	1	5
80 - 90	3	15
70 - 80	1	[illegible]
60 - 70	3	15
50 - 60	2	10
40 - 50	1	5
30 - 40	1	5
20 - 30	2	10
10 - 20	1	5
0 - 10	3	15

AVERAGE TIME	20	MEAN	79.4
No. OF POINTS	10	MIN	22.7
No. NO DATA	0	MAX	21[illegible].4
POINTS SAMPLED	200	σ	5[illegible]
SAMPLING VOLUME	~ 2.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	1	10
90 - 100	0	0
80 - 90	0	0
70 - 80	2	20
60 - 70	0	0
50 - 60	1	10
40 - 50	0	0
30 - 40	1	10
20 - 30	1	10
10 - 20	2	20
0 - 10	2	20

AVERAGE TIME	40	MEAN	79.4
No. OF POINTS	5	MIN	45.2
No. NO DATA	0	MAX	159.6
POINTS SAMPLED	200	σ	42.4
SAMPLING VOLUME	~ 4.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	1	20
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	1	20
30 - 40	1	20
20 - 30	1	20
10 - 20	0	0
0 - 10	1	20

AVERAGE TIME	60	MEAN	79
No. OF POINTS	3	MIN	44.3
No. NO DATA	0	MAX	139.6
POINTS SAMPLED	180	σ	43
SAMPLING VOLUME	~ 6.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	1	33.3
60 - 70	0	0
50 - 60	0	0
40 - 50	1	33.3
30 - 40	1	33.3
20 - 30	0	0
10 - 20	0	0
0 - 10	0	0

Table A17. Variability in Λ on 15 August 1979

(Λ = mm, sampling volume = m^3)

AVERAGE TIME	5	MEAN	2.792
No. OF POINTS	40	MIN	0.111
No. NO DATA	10	MAX	4.941
POINTS SAMPLED	190	σ	1.059
SAMPLING VOLUME	~ 0.57		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	1	3.33
80 - 90	0	0
70 - 80	1	3.33
60 - 70	1	3.33
50 - 60	2	6.67
40 - 50	6	20
30 - 40	0	0
20 - 30	4	13.3
10 - 20	6	20
0 - 10	[illegible]	30

AVERAGE TIME	10	MEAN	2.994
No. OF POINTS	20	MIN	0.583
No. NO DATA	0	MAX	4.692
POINTS SAMPLED	200	σ	1.224
SAMPLING VOLUME	~ 1.1		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	1	5
70 - 80	1	5
60 - 70	0	0
50 - 60	3	15
40 - 50	4	20
30 - 40	1	5
20 - 30	3	15
10 - 20	1	5
0 - 10	6	30

AVERAGE TIME	20	MEAN	3.552
No. OF POINTS	10	MIN	1.826
No. NO DATA	0	MAX	4.423
POINTS SAMPLED	200	σ	0.835
SAMPLING VOLUME	~ 2.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	1	10
30 - 40	1	10
20 - 30	3	30
10 - 20	1	10
0 - 10	4	40

AVERAGE TIME	40	MEAN	4.122
No. OF POINTS	5	MIN	3.665
No. NO DATA	0	MAX	4.525
POINTS SAMPLED	200	σ	0.344
SAMPLING VOLUME	~ 4.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	0	0
20 - 30	0	0
10 - 20	1	20
0 - 10	4	80

AVERAGE TIME	60	MEAN	4.176
No. OF POINTS	3	MIN	3.833
No. NO DATA	0	MAX	4.379
POINTS SAMPLED	180	σ	0.244
SAMPLING VOLUME	~ 6.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	0	0
20 - 30	0	0
10 - 20	0	0
0 - 10	3	100

Table A18. Variability in AD_m on 15 August 197[illegible] (sampling volume [illegible] m^3)

AVERAGE TIME	[illegible]	MEAN	[illegible]
No. OF POINTS	[illegible]	MIN	0.14
No. NO DATA	[illegible]	MAX	[illegible]
POINTS SAMPLED	[illegible]	σ	1.64
SAMPLING VOLUME	~ [illegible]		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	[illegible]	[illegible].33
80 - 90	0	0
70 - 80	0	0
60 - 70	[illegible]	10
50 - 60	4	13.33
40 - 50	[illegible]	16.67
30 - 40	4	13.33
20 - 30	3	10
10 - 20	[illegible]	16.67
0 - 10	[illegible]	16.67

AVERAGE TIME	10	MEAN	[illegible]
No. OF POINTS	20	MIN	[illegible]
No. NO DATA	0	MAX	7.74
POINTS SAMPLED	200	σ	2.06
SAMPLING VOLUME	~ 1.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	2	10
70 - 80	2	10
60 - 70	1	[illegible]
50 - 60	[illegible]	[illegible]
40 - 50	0	0
30 - 40	[illegible]	[illegible]
20 - 30	2	10
10 - 20	4	20
0 - 10	[illegible]	[illegible]

AVERAGE TIME	20	MEAN	[illegible].91
No. OF POINTS	10	MIN	2.27
No. NO DATA	0	MAX	8.09
POINTS SAMPLED	200	σ	1.39
SAMPLING VOLUME	~ 2.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	1	10
50 - 60	1	10
40 - 50	0	0
30 - 40	2	20
20 - 30	1	10
10 - 20	3	30
0 - 10	2	20

AVERAGE TIME	40	MEAN	7.33
No. OF POINTS	[illegible]	MIN	5.79
No. NO DATA	0	MAX	9.11
POINTS SAMPLED	200	σ	1.2
SAMPLING VOLUME	~ 4.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	0	0
20 - 30	2	40
10 - 20	1	20
0 - 10	2	40

AVERAGE TIME	60	MEAN	7.67
No. OF POINTS	3	MIN	6.64
No. NO DATA	0	MAX	9.34
POINTS SAMPLED	180	σ	1.19
SAMPLING VOLUME	~ 6.2		

CLASS PERCENT FROM MEAN	NUMBER IN CLASS	PERCENT IN CLASS
>100	0	0
90 - 100	0	0
80 - 90	0	0
70 - 80	0	0
60 - 70	0	0
50 - 60	0	0
40 - 50	0	0
30 - 40	0	0
20 - 30	1	33.33
10 - 20	1	33.33
0 - 10	1	33.33

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